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Study on the Concentration of Contaminants in the Toilet of the Teaching Building of Henan University of Science and Technology

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Abstract

In order to explore the diffusion and distribution law of concentration of the contaminants in the toilet under natural ventilation, computational fluid dynamics method was used to simulate and analyze the concentration of the contaminant based on the toilet of the teaching building of Henan University of Science and Technology. The height of 0.8m and 1.5m from the ground were taken as the human breathing area. On this basis, in order to explore the distribution of concentration of the contaminants in the toilet after the ventilation form is optimized, the concentration in the toilet under three different "natural ventilation+mechanical exhaust" working conditions were simulated. The results show that the concentration of the contaminant in the toilet of the teaching building of Henan University of Science and Technology is mainly released by the defecation pool, while the contaminants released by the urinal have little influence, and the contaminants are mainly distributed at the bottom of the bathroom. Under the ventilation form of "natural ventilation", vortex is formed in the local area of the toilet, leading to poor ventilation effect. Under the ventilation form of "natural ventilation+mechanical exhaust", the local vortex area is obviously reduced, and the ventilation effect is the best when the mechanical exhaust outlet is set in the lower part.

Keywords

Toilet; Concentration of Contaminants; Air Quality; Natural Ventilation; Mechanical Ventilation.

1. Introduction

Nowadays, the ventilation design of university toilets is still dominated by natural ventilation due to the limitations of university teaching buildings. This type of ventilation is carried out by the pressure and circulation of external air. Compared with mechanical ventilation using mechanical equipment to achieve indoor ventilation, natural ventilation depends more on external natural conditions [1]. However, due to the unreasonable size and relative position of the air outlet and air inlet in the toilet, the natural ventilation efficiency is reduced, which will not only affect the appearance of the university, but also reduce students' enthusiasm for learning in the teaching building. Therefore, it is of great practical significance to study and improve the diffusion and distribution of contaminant concentrations in the toilets of the teaching building.

At present, most domestic and foreign researchers use CFD simulation and experimental measurement to study the air quality of toilets. Yongan Ao [2] et al. simulated the impact of different mechanical exhaust conditions and positions on the concentration of toilet air pollution. Shaojie Ji et al. [3] simulated the pollutant concentration in the toilet of the teaching building with CFD, and evaluated the simulation results with the concentration of ammonia and hydrogen sulfide. It was indicated that when the height of the toilet baffle is 0.15 m, the pollutant concentration is the lowest. Yang Wang [4] and others studied the ammonia concentration in public toilets under different working conditions. Jiaqi Cao [5] and others found that in rainy seasons, mechanical ventilation could not rapidly reduce the relative humidity of the air in the toilets. G. He [6] et al. simulated the contaminant distribution under different ventilation modes in the sample room by combining experiments and simulation. The results showed that the pollution source has a great influence on the indoor contaminant concentration distribution.

To sum up, there are few studies on public toilets at home and abroad. For public toilets in universities, there are many users, and most of the toilets use natural ventilation mode. In the design of natural ventilation mode, more consideration should be given to the reasonable selection of ventilation volume and ventilation conditions. Therefore, computational fluid dynamics method is applied in this paper to simulate and analyze the contaminant concentration in the toilets of the public education building of Henan University of Science and Technology under natural ventilation, so as to explore the diffusion and distribution rules of contaminant concentration in the toilets of the public education building under natural ventilation. On the basis of natural ventilation, by optimizing the ventilation, the concentration distribution of contaminants in the toilets of Henan University of Science and Technology public education building under three different conditions of "natural ventilation+mechanical exhaust" was analyzed.

2. Theoretical Model

The numerical simulation method is based on the principle of Computational Fluid Dynamics and computer technology. It is difficult for the contaminant concentration distribution in the toilets of Henan University of Science and Technology to reach a stable state, so the transient mode is selected for solution in the paper. In order to satisfy the calculation accuracy and convergence performance, the standard k-e turbulence model is selected and the control equation which is based on the pressure solver.

Continuity equation:

$$-\iint_{CS_1} \rho v \bullet dA - \iint_{CS_2} \rho v \bullet dA = \frac{\partial}{\partial t} \iiint_{CV} \rho dV \tag{1}$$

CS_1 and CS_2 are the inlet and outlet surfaces of the control volume, and CV is the total volume of the control volume.

Momentum equation:

$$\iiint_{CV} \rho f dV + \oint\!\!\oint_{CS} f_s dA - \iint_{CS_1} (n \bullet v) \rho v dA - \iint_{CS_2} (n \bullet v) \rho v dA = \frac{\partial}{\partial t} \iiint_{CV} \rho v dV \tag{2}$$

f (N) is the mass force per unit mass, fs(N) is the surface force per unit surface, and CS is the total surface.

Energy equation:

$$\frac{dE}{dt} = \frac{dw_f}{dt} + \frac{dw_{fs}}{dt} + \frac{dQ}{dt} \tag{3}$$

E is the total energy, $\frac{dw_f}{dt}$ (J/s) is the work done in unit time of mass force, $\frac{dw_{fs}}{dt}$ (J/s) is the work done by the surface force in unit time, and Q(W) is the total power of the external heat source.

3. Calculation Model

3.1 Geometric Model

In this paper, the toilets are simplified. According to the measurement, a simplified geometric model is established, which is composed of doors, partitions, windows, defecation pools, urinals and toilet

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baffles. The location of the internal structure of the toilet is shown in Fig 1.

As is shown in Fig 2-4, 0.5 square meters of mechanical exhaust outlet is added at different positions in the toilet, three different ventilation forms of "natural ventilation+mechanical ventilation" are arranged.

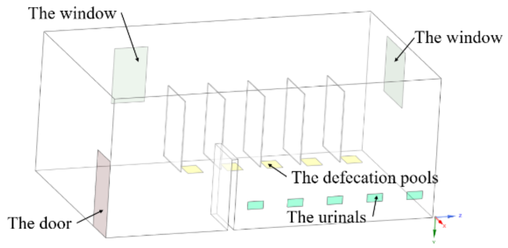

Fig 1. Geometric model under "natural ventilation"

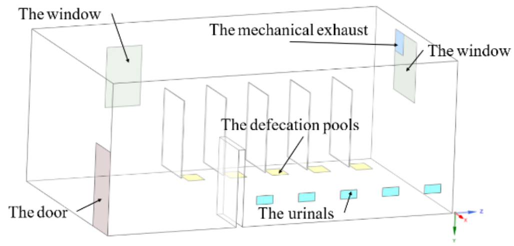

Fig 2. Geometric model of "natural ventilation+back mechanical ventilation"

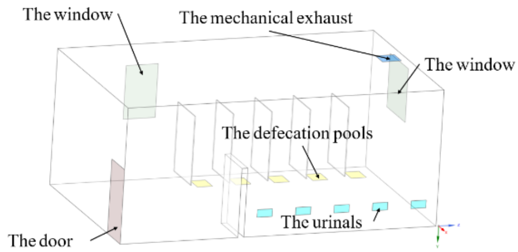

Fig 3. Geometric model under "natural ventilation+top mechanical ventilation"

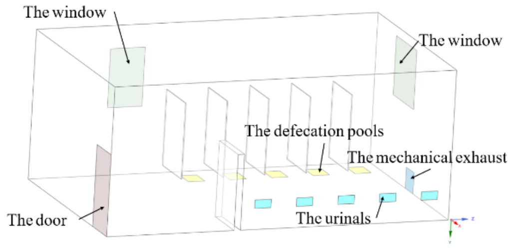

Fig 4. Geometric model under "natural ventilation+lower mechanical ventilation"

3.2 Boundary Condition

Boundary condition is an important part of Fluent simulation and plays a decisive role in the simulated results. The boundary condition should be set in accordance with the reality. They are set as follows: The door is set as the velocity inlet boundary. In this Paper, the door only releases air, and the inlet velocity is 1m/s. The windows are set as free exit boundary condition, walls and diaphragms are set as wall boundary condition. The defecation pools are set as the velocity inlet boundary. And the defecation pools only releases hydrogen sulfide, not ammonia, the release rate is 0.1m/s. Urinals are set as the velocity inlet boundary. And the urinals only releases ammonia, not hydrogen sulfide, and the release rate is 0.1m/s. Mechanical exhaust is set as the outlet boundary condition of exhaust fan. The standard atmospheric pressure is used for simulation, the initial temperature is 25 °C, and the inlet temperature of the defecation pools and urinals is 37 °C.

3.3 Mesh Generation

In this paper, ICEM is used for mesh generation. In order to more accurately simulate the flow field close to the reality, the grid is densified at the air inlet, air outlet, partition, wind barrier, mechanical exhaust outlet and urinals. The division results are shown in Figure 5 and Figure 6

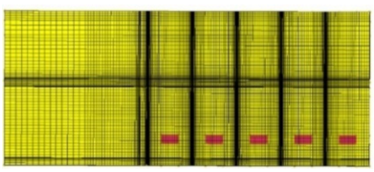

Fig 5. Local mesh densification at urinal

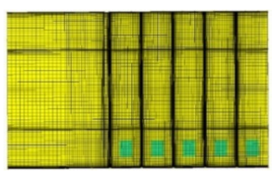

Fig 6. Local mesh densification at the defecation pools

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4. Result and Analysis

4.1 Working Condition of Division

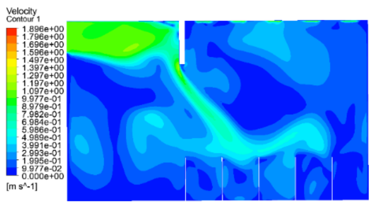
In order to explore the diffusion and distribution law of concentration of the contaminants in the public education toilet of HEUST under the "natural ventilation" and three different "natural ventilation+mechanical exhaust" ventilation forms, four working conditions are divided in this paper, as shown in Table 1.

Table 1. Working condition of calculation

working condition	Ventilation situation	contaminant
1	natural ventilation	ammonia / hydrogen sulfide
2	natural ventilation+mechanical	ammonia / hydrogen sulfide
3	natural ventilation+mechanical	ammonia / hydrogen sulfide
4	natural ventilation+mechanical	ammonia / hydrogen sulfide

4.2 Velocity Distribution in Breathing Area of Toilet

In this paper, the height of 0.8m and 1.5m from the ground are selected as the cross-section of human breathing area. It is set that only ammonia gas diffuses in urinals and only hydrogen sulfide gas diffuses in defecation pool. The velocity distribution of cross-section of breathing area under four working conditions is shown in Fig 7.


(a) Velocity cloud image at the height of 0.8m under working condition 1


(b) Velocity image chart at the height of 0.8m under working condition 2


(c) Velocity cloud image at the height of 1.5m under working condition 3


(d) Velocity cloud image at the height of 1.5m under working condition 4

Fig 7. Cloud image of cross-section velocity field in breathing area

As can be seen from Figure 7, under the condition of natural ventilation, the wind flowing in the doorway spreads upward due to the partition wall, and then flows through the defecation pool area, forming vortex in local areas. Then the air stagnation area is formed in the toilet, which leads to poor air flow. When mechanical ventilation is added, the air flow that spreads upward is blocked by the partition wall, flows through the defecation pool area, and then flows to the mechanical exhaust outlet, which makes the local vortex area significantly smaller. Among the three kinds of mechanical ventilation, the lower mechanical ventilation has the best effect.

4.3 Ammonia Mass Fraction Distribution in Toilet

The distribution of ammonia mass fraction in cross-section of breathing area under four working conditions is shown in Fig 8.

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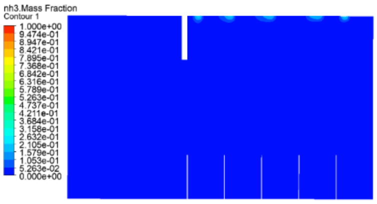
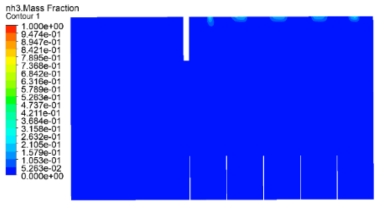
(a) Cloud image of ammonia mass fraction at the height of 0.8m under working condition 1

(b) Cloud image of ammonia mass fraction at the height of 0.8m under working condition 2



(c) Cloud image of ammonia mass fraction at the height of 1.5m under working condition 3



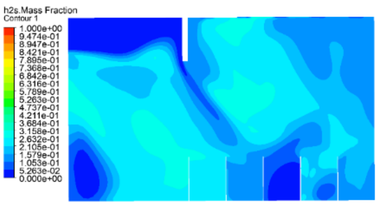
(d) Cloud image of ammonia mass fraction at the height of 1.5m under working condition 4

Fig 8. Cloud image of ammonia mass fraction in breathing area

It can be seen from figure 8 that the mass fraction of ammonia gas in two sections of 0.8m and 1.5m above the ground is almost the same under four working conditions. Among them, the mass fraction of ammonia gas is relatively low on the section of 1.5m above the ground because it is far from the urinals. Because the density of ammonia gas is lower than that of air, most of the ammonia gas released from urinals diffuses upward, and hardly diffuses into the internal space. For the two sections of the human breathing area, the ammonia concentration is very low, and it is concentrated near the urinals, which causes little pollution to the toilet. Therefore, the hydrogen sulfide released from the urinals is the main pollutant source, and its slight influence can be ignored in the study.

4.4 Hydrogen Sulfide Mass Fraction Distribution in Toilet

The cloud image distribution of hydrogen sulfide mass fraction in the breathing area section under four working conditions is shown in Fig 9.



(a) Hydrogen sulfide mass fraction at the height of 0.8m under Working condition 1

(b) Hydrogen sulfide mass fraction at the height of 0.8m under condition 2

(c) Hydrogen sulfide mass fraction at the height of 1.5m under condition 3

(d) Hydrogen sulfide mass fraction at the height of 1.5m under condition 4

Fig 9. Cloud image of hydrogen sulfide mass fraction in the breathing area

As shown in Figure 9, because the door is an air inlet, the hydrogen sulfide mass fraction near the door is relatively low, and the density of hydrogen sulfide is greater than that of air. Under the four working conditions, the hydrogen sulfide mass fraction at the height of 0.8m is far greater than that at the height of 1.5m, and hydrogen sulfide is easier to gather at the bottom. Therefore, the hydrogen sulfide mass fraction is the least when the mechanical exhaust is set at the bottom, and the improvement effect is most obvious.

5. Conclusion

In order to explore the diffusion and distribution law of concentration of the contaminant in the toilet under natural ventilation, computational fluid dynamics method was used to simulate and analyze the concentration of the contaminant based on the toilet of the teaching building of the Henan University of Science and Technology. The height of 0.8m and 1.5m from the ground were taken as the human breathing area. On this basis, in order to explore the distribution of concentration of the contaminant in the toilet after the ventilation form is optimized, the concentration in the toilet under three different "natural ventilation+mechanical exhaust" working conditions were simulated. The results are as follows:

(1) The contaminants in the public education toilets are mainly released by the defecation pools. The impact of contaminants released from the urinals is very small and can be ignored, and the contaminants are mainly distributed at the bottom of the toilets.

(2) Under the form of "natural ventilation", vortex is formed in local areas of the toilet, which has a poor ventilation effect, leading to the inability to effectively discharge contaminants in the area, and the ammonia mass fraction in the breathing area section is very low. Hydrogen sulfide is the main contaminant.

(3) The concentration of contaminants can be effectively reduced under the ventilation form of "natural ventilation+mechanical exhaust" in the toilet. And the mechanical exhaust outlet is set at the lower part for the best effect, which can better ensure the air quality of the toilet.

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